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Application practice of foam-assisted oxygen-reducing air flooding in ultra-low permeability reservoirs in Jiyuan area

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Abstract

G271 Chang 8 in JY Oilfield is a typical ultra-low permeability reservoir. During the waterflooding development process, it faces many problems such as rapid water cut rise, large decline, complex plane water flooding characteristics, difficult energy replenishment, and low water flooding recovery. In order to improve the water flooding effect of the reservoir, a foam-assisted oxygen-reducing air flooding experiment was carried out. Through field practical application, the following five aspects of understanding are obtained: 1. During the process of air foam flooding, the flooding fluid produces the Jia-min effect in the seepage channel, which can effectively block the high-permeability zone, and the low-permeability channel can increase the swept range and increase oil washing. Efficiency; 2. Air foam flooding has a good effect on improving the longitudinal profile of reservoirs with different sedimentary rhythms, and the water flooding profile is uniform; 3. The plane flooding tends to be balanced, and the corresponding well groups have obvious effects, which are divided into water cut reduction, obvious oil increase and 4. Compared with the water injection area, the formation energy remains sufficient in the cavitation flooding test area, and the effect of controlling water and stabilizing oil is obvious. The practical research results have important guidance and reference for the effective development of air foam flooding in ultra-low permeability reservoirs.

Keywords

Ultra-low permeability reservoir; water flooding; nitrogen foam flooding; enhanced oil recovery.

1. Geological background

The G271 ultra-low permeability reservoir in Jiyuan Oilfield is located in the west of the middle section of the northern Shaanxi slope. In the Chang 8 oil layer, the reservoir is buried deep (2500-2800m), with poor reservoir physical properties, with an average permeability of only 0.38mD and an average porosity of 8.6%. Fractures are developed in the middle and north of the reservoir, and the pores are relatively small and some are isolated and disconnected, resulting in strong spatial heterogeneity of seepage in the reservoir after fracturing. With the extension of oilfield development time, the development process of the oil reservoir is affected by the physical properties of the reservoir, fractures and well pattern, etc., and faces the contradiction of rapid water cut rising speed and large gradient, and the reservoir plane and profile water flooding characteristics are complex. Difficulty in energy supply and low water flooding recovery.

2. Mechanism of cavitation displacement

Air foam flooding is an efficient recovery method after water flooding and gas flooding. By adding foam to the gas, the two flooding advantages of gas injection and foam can be combined, and the flooding can be adjusted while being flooded. Nitrogen can effectively supplement the formation energy, and at the same time use foam to increase the apparent viscosity of the gas phase, change the gas-liquid ratio, and play the advantages of "blocking large but not small, blocking water but not oil" when the formation is plugged, thereby increasing the high permeability reservoir. The flow resistance of the layer microchannel can improve the sweeping range of gas in the low-permeability channel, increase the oil washing efficiency and the blocking effect of large pores and roars. Its mechanism of action mainly includes three categories: the mechanism of gas-liquid gravity separation, the mechanism of selective plugging of pores and throats, and the mechanism of surfactant washing oil.

2.1. Mechanism of gas-liquid gravity differentiation

During the seepage migration of nitrogen foam in the reservoir flow, the bubble polymer in the foam undergoes obvious differentiation under the action of gravity, the fluid will gradually migrate downward, and the bubble will gradually rise due to the difference in density. The foam liquid film gradually becomes thinner, and the surface tension of the bubble exceeds a certain level and ruptures, resulting in gas-liquid separation. Because the gas differentiated from the bubble burst in the foam liquid migrates to the top of the pore throat channel to form a higher pressure area - the gas cap, which increases the gas drive energy to the reservoir, and the gas molecules in the top area have a smaller radius and can enter a narrower throat. It can convert the fluid in the original reservoir from the bound state into movable fluid and be produced. At the same time, the gravity-differentiated nitrogen gas itself also has expansibility, which is also conducive to maintaining the formation pressure level, to a certain extent. It can effectively increase the elastic energy of the formation and better displace the reservoir fluid; the viscosity of the foaming agent is slightly higher, which can also effectively reduce the mobility ratio of the displacement fluid and the oil, making the oil in the reservoir easier to displace.

2.2. The mechanism of selective plugging of pore throats

The selective pore-throat plugging mechanism of nitrogen foam flooding leads to the characteristics of “blocking big but not small, blocking water but not oil”. According to these two different characteristics, it can be divided into two corresponding action mechanisms. 1. "Blocking big but not small" or "blocking high but not blocking low": in the middle and late stages of development, the seepage channels with large pores in the reservoir have the characteristics of higher water content and lower oil saturation than smaller pores and low permeability channels . The foam fluid will preferentially enter the large pores, and the pore capillary force will cause the fluid to have a significant hindering effect on the fluid - the Jia Min effect, which will effectively block the high-permeability channel, so that the subsequent injection fluid will flow to the medium and low-permeability small pores. Regional seepage. At the same time, the nitrogen gas injected into the formation itself is also compressible, and it is easy to enter the area of medium and low permeability small pores, which expands the swept range. 2. "Water blocking but not oil blocking": Nitrogen foam has the characteristics of "foaming in contact with water and defoaming in contact with oil". In high-permeability channels of reservoirs with high water content, a large number of foams will be formed and become more stable and hinder fluid migration. However, in the area with high oil saturation in the low-permeability channel, it will defoaming and dissolve into the crude oil, resulting in an increase in the volume of the crude oil mixture, a decrease in viscosity, an increase in fluidity, and a reversal of the migration path of the displacement fluid, which can effectively improve the oil production. Reservoir flooding efficiency.

2.3. The mechanism of action of surfactants in oil washing

The air foam flooding fluid itself contains a large number of surfactant molecules. When injected into the formation, a large number of bubbles can be formed when it encounters gas. The internal gas pressure is different and the foam size is different, resulting in a large difference in the density of the foam and the flooding fluid. Therefore, after the foam is formed in the liquid, it will soon rise to the surface of the liquid to form a bubble polymer. Among them, the internal pressure of large bubbles is small, and the internal pressure of small bubbles is large. The larger the bubbles, the faster the floating speed. The gaps between the bubbles are small and tight, the existence time is short, and the stability of the foam is relatively poor; on the contrary, the smaller the bubbles are. , the rising speed is slower, the surface free energy is smaller, and the stability of the formed foam is better. Therefore, the bubble polymer can be regarded as a fluid with high surface activity, and its foam liquid has the characteristics of reducing the oil-water interfacial tension, emulsifying the crude oil and changing the wettability of the reservoir during the oil displacement process.

3. Field practical application

3.1. Cavitation flooding stage

(1) The first stage: In 2016, a single well injection test (2 injection and 11 production) was carried out. In this stage, the injection parameters of this stage are: daily gas injection of 15-20m3, daily foam injection of 12-15m3, gas-liquid ratio 1.0-1.5, injection-production ratio 2.0-2.5. The main purpose is to evaluate the air foam injectability of the G271 Chang 8 reservoir, and to provide data and accumulate experience for the pilot test of oxygen-reduced air foam flooding in this area.

(2) From 2017 to 2019, the expansion test group (5 injections and 26 productions) will be carried out: 4 injection wells will be added successively on the basis of the test injection test: 5 injections and 26 productions will be formed. The injection parameters of this stage are 22.4m3 gas injection per day, 15-20m3 foam injection per day, gas-liquid ratio 1.0-1.5, and injection-production ratio 2.5-3.0. After the main well is effective, the water content rises rapidly, and the gas is quickly flooded. Optimize injection and production parameters to promote oil well effectiveness.

(3) From 2019 to the present (5 injections and 18 productions), the main water-flooded oil wells were shut down, and the parameters were adjusted to inject 22.4m3 gas per day, 15m3 foam per day, gas-liquid ratio 1.5, and injection-production ratio 2.5-3.0. The water cut is stable, and the lateral wells are effective.

3.2. Cavitation Displacement Effect

3.2.1. Obvious plugging effect on high-permeability channels in reservoirs

The size of the foam plugging capacity plays a key role in whether the displacement technology in the air foam flooding test area can achieve oil displacement while plugging water. The external fluid injected into the formation is mainly affected by the capillary resistance of the pores and the obstruction of the stable foam in the high-permeability zone, which effectively blocks the large pores, which in turn leads to the reversal of the seepage path of the fluid and improves the recovery efficiency of the reservoir. At present, the average gas injection pressure of the five test wells in the test area is 23.25↑29.50MPa, and the highest is 30.0MPa; the liquid injection pressure is 22.93MPa↑27.64MPa, and the highest is 28.1MPa; the oil well formation test pressure in the test area is 14.7MPa↑18.5MPa, steadily increasing year by year. Before and after the test in the cavitation zone, the gas-liquid injection pressure increased steadily on the whole, the formation energy was sufficient, and the formation pressure of the oil well was stable, indicating that the air foam effectively blocked the high-permeability channels in the formation.

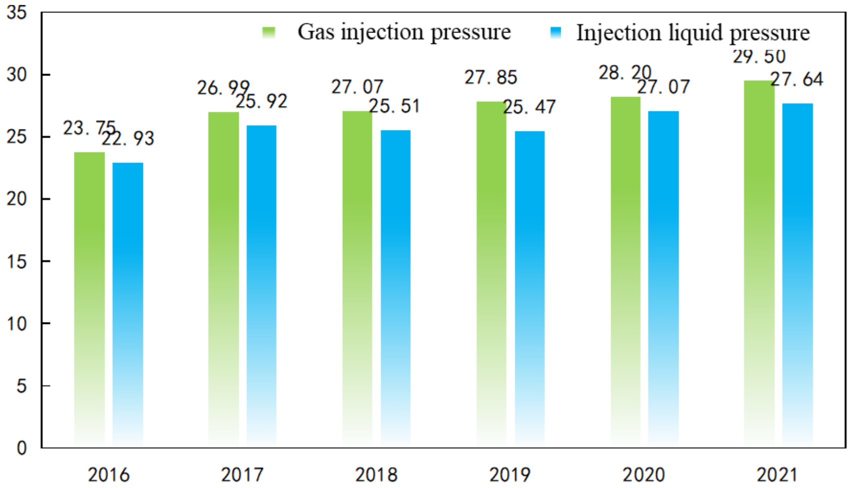

Fig. 1 Statistical histogram of injection pressure in cavitation area of G271 reservoir

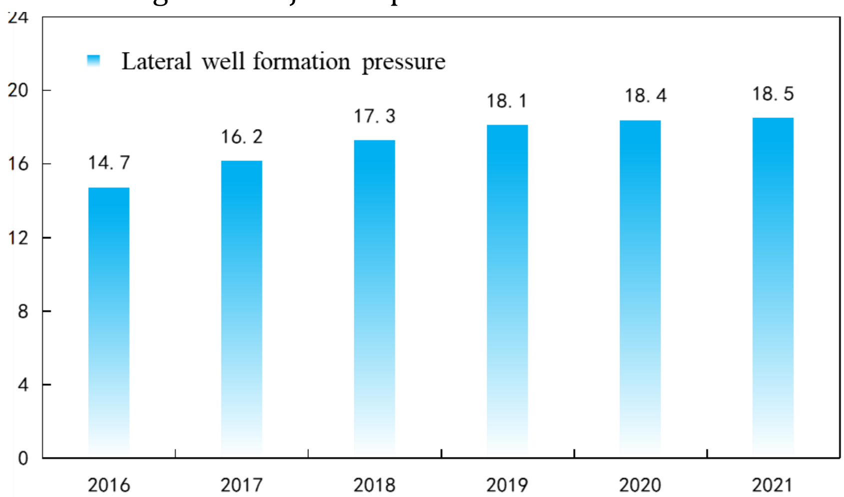

Fig. 2 Statistical histogram of formation pressure in cavitation area of G271 reservoir

3.2.2. Longitudinal profile of reservoirs with different rhythms is more uniformly injected

The test block is mainly composed of underwater distributary channel sedimentary microfacies, the lower part is dominated by fine sandstone, and the upper part is siltstone and argillaceous siltstone, showing a positive rhythm from bottom to top. Block bedding and oblique bedding are developed, and bedding fractures are relatively developed. The logging gamma curve shows an obvious box shape, and the overall resistivity curve is a relatively stable high resistance. Affected by the depositional environment, the water absorption state has a significant positive correlation with the physical properties and saturation of the reservoir rhythm layer. The average water absorption thickness of a single well is 8.5m↑9.3m, and the water absorption profile changes from finger shape to peak shape gradually to uniform water absorption. The ratio increased from 50↑60% to 10%; the water driving degree increased from 75.6%↑76.7%, and the water absorption profile gradually became better, indicating that cavitation flooding has a significant effect on improving the water absorption status of the positive rhythm profile, and at the same time, it improves the longitudinal direction of the reservoir. use.

3.2.3. The effect of well group is obvious, and the plane displacement tends to be balanced

The air foam flooding test area has been tested since 2016. The originally designed total injection volume of air foam was 58.97×104m3 (0.5PV), but now 27.95×104m3 (0.2PV) has been injected, and the injection ratio is 47.4%. It is now in the second stage of the test. .

According to the development and research experience of predecessors, the effective types of oil wells in the cavitation area are mainly divided into three types: obvious oil-increasing type, decline slowing type and water-cut reduction type, among which the obvious oil-increasing type is the main type of effectiveness. This paper mainly focuses on the statistical analysis of water injection, gas injection, liquid production, oil production and water content of all wells in the current test area.

Water cut type: This type mainly occurs in the first stage of the test (2 injection and 13 production), with 4 effective wells, and the effective rate is 30.7%, including 3 main fracture wells and 1 lateral well, which is effective in 2-3 months The effect is immediate, but the duration of the effect is short, the water content rises rapidly in the later stage, and most of the main wells are flooded. During the effective period, the average daily oil increase of a single well was 0.2t, and the water cut was reduced from 43.2 to 22.7%. This type has a quick effect, but the effect lasts for a short time. After that, the water cut rises rapidly, the plugging fails, and the fractures are mainly flooded to the oil well.

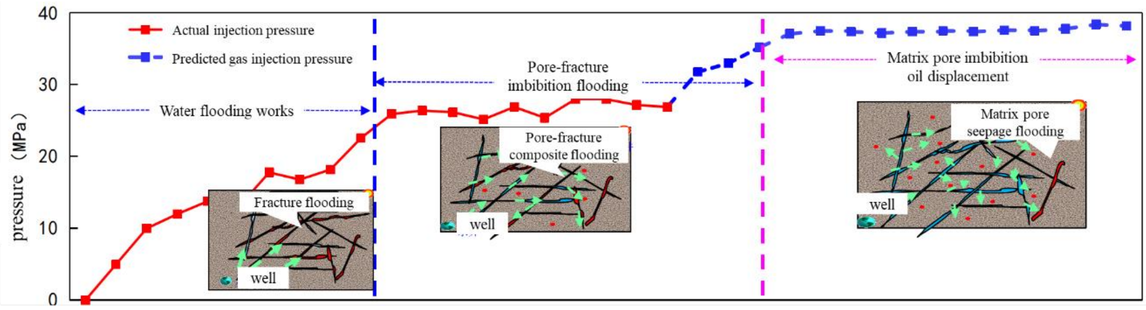

Fig. 3 Schematic diagram of seepage mechanism at different flooding stages in the air foam flooding test area

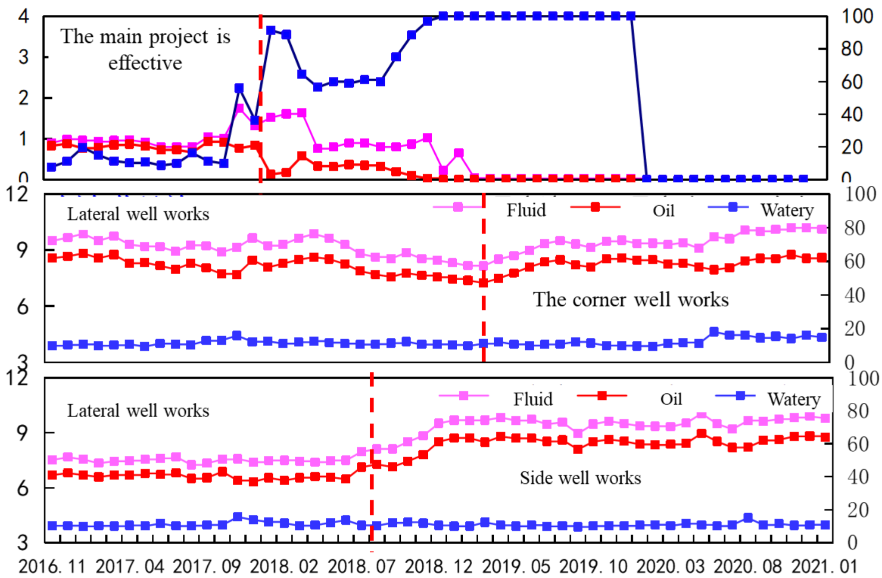

Fig. 4 Production curve of effective oil wells in cavitation flooding test area

Decreasing and slowing type: Mainly in the second stage of the test (5 injections and 26 productions), 5 new effective wells were added, and the effective rate was 34.6%. Among them, 2 main fractured wells and 3 lateral wells were effective, and the lateral wells were mainly corner wells, which were effective The cycle is 8-15 months, the effect time is slow, but the duration is longer. During the effective period, the daily oil increase of a single well was 0.15t.

Obvious oil-increasing type: It mainly occurs in the second stage of the test (5 injection and 18 production), and the water cut rises rapidly after the main direction well of the fracture takes effect, and 9 main direction wells are flooded. After shutting down 8 main water-flooded wells, 10 lateral oil wells became effective, with an effective effect ratio of 55%. The overall effective time was long. Among them, the corner wells were effective first, and the effective period was 6-10 months. The daily oil increase of a single well was 0.21 t, the effective period of side wells is 9-12 months, and the daily oil increase of single well is 0.20t.

To sum up, in the initial stage of foam flooding, the main direction of fractures is effective first, and the effective types are mainly water cut type, with short effective period and short duration; secondly, lateral wells are effective, and the effective types are oil-increasing type and decline-releasing type. However, the effective duration is long, and the effect of air foam flooding to control water and stabilize oil is obvious.

3.2.4. The effect of water control and oil stabilization in the test area is obviously better than that in the water injection area

The formation energy in the air foam flooding test area is well maintained and the energy is relatively sufficient. The formation pressure before and after increases by 12.3↑17.1MPa year by year, and the pressure maintenance level increases significantly by 65.7%↑91.4%, which is significantly larger than that in the water injection area. After the air bubble, the formation energy in the test area was supplemented, and the main formation pressure remained stable at 27.0↓26.8MPa; the lateral well pressure was 14.7↑18.4MPa, increasing year by year. The main lateral pressure difference is 14.7↓9.5MPa, decreasing year by year. The lateral well pressure in the cavitation area remains at a level of 78.7↑98.3%, and the lateral well pressure in the adjacent water injection area maintains a level of 87.8↑88.8%. The lateral well pressure in the cavitation area is generally slightly higher than that in the adjacent water injection area.

The comprehensive water content of the test area decreases year by year, and the water control effect has obvious advantages. The water content rise rate is -0.6%, which is relatively stable in the early stage of the test. The water content rise rate is 0.3%. The comprehensive water content of the water injection area is increasing year by year. The decline advantage of the foam flooding stage in the test area is also very obvious, the decline is -0.1%, and the water injection area in the same period has a decline of 0.9%, showing an increasing trend. In summary, the formation energy in the air foam area remains sufficient, and the water control and oil stabilization effect is significantly better than that in the water injection area.

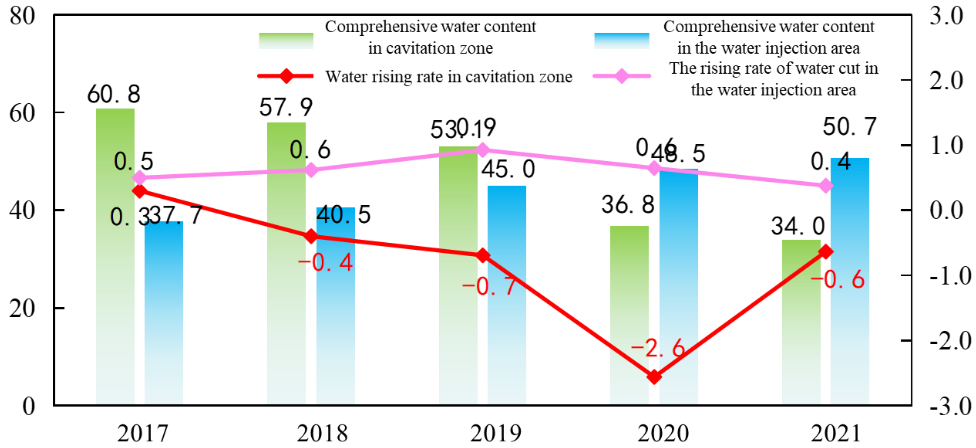

Fig. 5 Changes of water content and water rise rate in cavitation area/water injection area

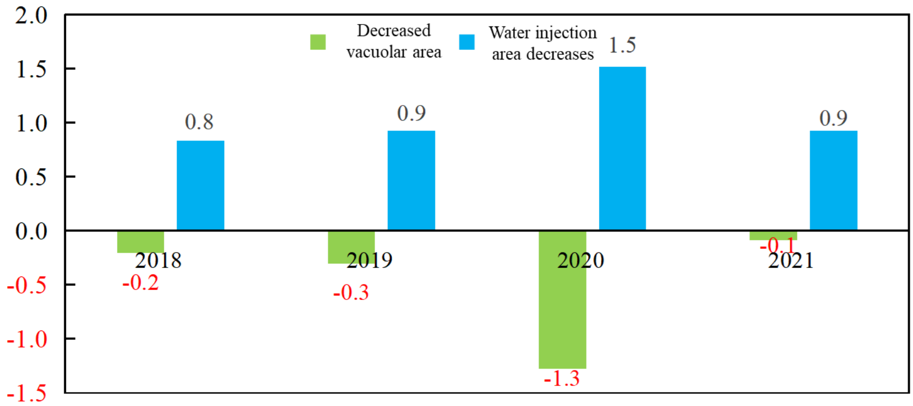

Fig. 6 Histogram of decreasing change in cavitation area/water injection area

3.2.5. The recovery rate of the test area is significantly improved

The overall injection effect of the air foam flooding test area is obvious. After optimizing the injection parameters, the regional oil increases significantly, the water cut decreases, and the average daily oil increase of a single well is 0.20t. At present, the curve of water cut and recovery degree of the block is obviously shifted to the right. It is estimated that the dynamic recovery factor has increased from 18.5% to 25.0%, and increased by 6.5%, and the overall development situation has been significantly improved.

4. Conclusion

G271 Chang 8 is a typical ultra-low permeability reservoir, with obvious characteristics of low porosity and low permeability, well-developed fractures, relatively small roars and poor connectivity, resulting in strong spatial heterogeneity of reservoir seepage after fracturing . In the later development stage, the remaining oil between layers and wells accumulates and is not used, and the degree of recovery is low.

Air foam flooding test after water flooding in this area. In the initial stage, the Jiamin effect was continuously generated in the high-permeability area of the throat and fractures, and the large-pore high-permeability channel was blocked to transform the seepage path into the small-pore and low-permeability area, which played a significant role in sealing. blocking effect. Later, in the low permeability area, the original sweeping range can be expanded, the oil washing efficiency can be increased, and the oil recovery factor can be improved.

Affected by the depositional environment, the water absorption state has a significant positive correlation with the physical properties and saturation of the reservoir rhythm layer. The water absorption profile changes from finger shape to peak shape and gradually becomes uniform water absorption. The proportion of uniform water absorption increases, and the water absorption profile is obviously better. , indicating that cavitation flooding can significantly improve the water absorption of the positive rhythm profile, and at the same time improve the vertical production degree of the reservoir.

Plane displacement tends to be balanced, and the corresponding well groups have obvious effect characteristics. The types of oil well effectiveness are mainly divided into three categories: water cut decline type, obvious oil increase type and decline slowdown type. In the initial stage of foam flooding, the main direction of fractures is effective first, and the effective type is mainly water cut type, which is quick and lasts for a short time; the second is the lateral well, and the effective types are oil-increasing type and decline-releasing type, but the duration of effectiveness lasts for a long time. For a long time, the effect of air foam flooding to control water and stabilize oil is very obvious.

The formation energy in the air foam flooding test area is well maintained, the energy is relatively sufficient, the formation pressure gradually increases steadily, the water cut decreases year by year, and the decline slows down obviously. Compared with the adjacent water injection area, the effect of controlling water and stabilizing oil is obvious. After optimizing the injection parameters, the curve of water cut and recovery degree shifted to the right obviously, and the overall development situation was improved.

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